

EXPERIMENTAL VERIFICATION OF VAPOR DEPOSITION RATE THEORY IN
HIGH VELOCITY BURNER RIGS

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This research is motivated by gas-turbine hot-section component failures associated with accelerated "hot" corrosion to obtain a better understanding of the deposition phenomenon of corrosive species on turbine blades. A comprehensive yet tractable theoretical framework of deposition from combustion gases has been developed, covering the spectrum of various mass delivery mechanisms including vapor (refs. 1 and 2), thermophoretically enhanced small particle (ref. 3), and inertially impacting large particle (ref. 4) deposition. Rational yet simple correlations have been provided to facilitate engineering surface arrival rate predictions (refs. 5 to 7). The main objective of the program at the NASA Lewis has been the experimental verification of the corrosive vapor deposition theory in high-temperature, high-velocity environments. Toward this end, an atmospheric Mach 0.3 burner-rig apparatus has been built (fig. 1) to measure deposition rates from salt-seeded (mostly Na salts) combustion gases on an internally cooled cylindrical collector (ref. 8).

The results of the previous experiments have been reported in detail in reference 8. For sodium-salt seeded experiments there were two regions of disagreement between the deposition rate prediction of the chemically frozen boundary layer (CFBL), vapor-deposition theory and the experimentally observed deposition rates of Na_2SO_4 , depending on whether the collector temperature was above or below the melting point of Na_2SO_4 . Lower experimental deposition rate measurements for collector temperatures above the melting point of the deposit are attributed to the shear-driven molten deposit layer run-off from the smooth collector surface (ref. 9). Higher experimental values for collector temperatures below the melting point of the deposit, however, are explained by the presence of particles capable of inertially impacting the collector surface (cf. only Na-containing vapor species) and, subsequently, experimentally verified (refs. 10 and 11).

The elimination of particles (fig. 2) from the system was accomplished by dissolving sodium-acetate (Na source) in alcohol and mixing the alcohol solution with jet A-1 fuel in the fuel nozzle cavity before the mixture is sprayed into the combustor by the fuel nozzle. By this procedure (1) more residence time is provided

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to the solution droplets in the combustor (as compared with an air-atomized salt-solution probe spraying further downstream of the combustor), and (2) alcohol solution droplets mixed with jet A-1 fuel burn faster (as compared with slower vaporization of water solution droplets), thereby, giving sufficient time for the complete vaporization and reaction (to equilibrium) of all sodium-containing vapor species (fig. 3). Currently the total Na content of the combustion gases, corrected for losses on combustor liner walls (i.e., as seen by the collector), is obtained from sodium-acetate/alcohol solution feed rate.

For a typical burner-rig test specimen located in the cross-stream of the combustor-exit nozzle, the prediction of convective diffusion heat and mass transfer rates is complicated by the fact that the height and the diameter of the cylindrical target are comparable to, but less than, the diameter of the circular cross-stream jet (fig. 4). Experiments exploiting the naphthalene sublimation technique and duplicating the procedure of reference 12 as adapted to our setup (figs. 5 and 6), have been successfully completed to determine the heat and mass transfer coefficients (figs. 7 and 8). These experiments accompanied by additional experimental information on the effect of cross-stream jet cooling (dilution) due to the entrainment of stagnant room-temperature air (fig. 9) have enabled us to estimate heat and mass transfer rates for such large cylindrical geometries (ref. 13).

A parallel approach has been adopted to facilitate heat and mass transfer rate prediction by using a simpler collector geometry (fig. 10). Only a segment that is 20° on both sides of the forward stagnation point of the previous cylindrical targets is being used as the collection (deposition) surface, simulating the nose region of blades. The above-mentioned naphthalene sublimation technique has been further utilized to determine the heat and mass transfer coefficient of the stagnation-point region, as well as to determine the effects of main stream turbulence on heat and mass transfer rates for our burner rig deposition experiments. The other advantage of the segmented collector is the elimination of the cross-stream jet cooling (dilution) effect.

The deposition experiments on both types of collectors are currently underway. The agreement of the corrosive-salt vapor-deposition-rate predictions, based on the experimental information obtained for our system with preliminary data for Na_2SO_4 deposition experiments, is encouraging (fig. 11). More direct and precise knowledge of the sodium content of the combustion product gases in the cross-stream jet will be acquired with the installment of a sodium emission spectrometer. The availability of the high-pressure burner-rig facility will also enable us in the immediate future to study (1) the effect of pressure on deposition rates, and (2) dew point shifts.

REFERENCES

1. Rosner, D.E., et al.: Chemically Frozen Multicomponent Boundary Layer Theory of Salt and/or Ash Deposition Rates from Combustion Gases. Combust. Sci. Technol., vol. 20, no. 3/4, Sept. 1979, pp. 87-106.
2. Gökoğlu, S.A.; Chen, B.K.; and Rosner, D.E.: Computer Program for the Calculation of Multicomponent Convective Diffusion Deposition Rates from Chemically Frozen Boundary Layer Theory. NASA CR-168329, 1984.
3. Gökoğlu, S.A.: Thermophoretically Enhanced Deposition of Particulate Matter Across Nonisothermal Boundary Layers, Ph.D. Thesis, Yale Univ., 1983.
4. Fernandez de la Mora, J.; and Rosner, D.E.: Inertial Deposition of Particles

- Revisited and Extended: Eulerian Approach to a Traditionally Lagrangian Problem. PCH, PhysioChem. Hydrodyn., vol. 2, no. 1, 1981, pp. 1-21.
5. Gökoğlu, S.A.; and Rosner, D.E.: Correlation of Thermoporetically Modified Small Particle Diffusional Deposition Rates in Forced Convection Systems with Variable Properties, Transpiration Cooling, and/or Viscous Dissipation. Int. J. Heat Mass Trans., vol. 27, no. 5, May 1984, pp. 639-646.
 6. Israel, R.; and Rosner, D.E.: Use of a Generalized Stokes Number to Determine the Aerodynamic Capture Efficiency of Non-Stokesian Particles from a Compressible Gas Flow. Aerosol Sci. Technol., vol. 2, no. 1, 1983, pp. 45-51.
 7. Rosner, D.E.; Gökoğlu, S.A.; and Isreal, R.: Rational Engineering Correlations of Diffusional and Inertial Particle Depositon Behavior in Non-isothermal Forced Convection Environments. Fouling of Heat Exchanger Surfaces, Richard, W. Bryers, ed., Engineering Foundation, Inc., 1983, pp. 235-256.
 8. Santoro. G.J., et al.: Experimental and Theoretical Deposition Rates from Salt-Seeded Combustion Gases of a Mach 0.3 Burner Rig. NASA TP-2225, 1984.
 9. Rosner, D.E.; Günes, D.; and Nazih-Anous, N.: Aerodynamically Driven Condensate Layer Thickness Distributions on Isothermal Cylindrical Surfaces. Chem. Eng. Commun., vol. 24, no. 4-6, 1983, pp. 275-287.
 10. Santoro. G.J., et al.: Deposition of Na_2SO_4 From Salt-Seeded Combustion Gases on a High Velocity Burner Rig. High Temperature Corrosion in Energy Systems. Michael F. Rothman, ed., TMS-AIME Publication, 1985, pp. 417-434.
 11. Gökoğlu, S.A.; Experimental Verification of Vapor Deposition Model in Mach 0.3 Burner Rigs. NASA CP-2339, 1984, pp. 110-121.
 12. Sparrow. E.M.; Stahl. T.J.; and Traub, P.: Heat Transfer Adjacent to the Attached End of a Cylinder in Crossflow. Int. J. Heat Mass Trans., vol. 27, no. 2, Feb. 1984, pp. 233-242.
 13. Gökoğlu, S.A.; and Santoro. G.J.,: Determination of Convective Diffusion Heat/Mass Transfer Rates to Burner Rig Test Targets Comparable in Size to Cross-Stream Jet Diameter. To be presented at the 31st ASME International Gas Turbine Conference, Düsseldorf, Germany, June 8-12, 1986.

BURNER RIG SHORT EXIT NOZZLE

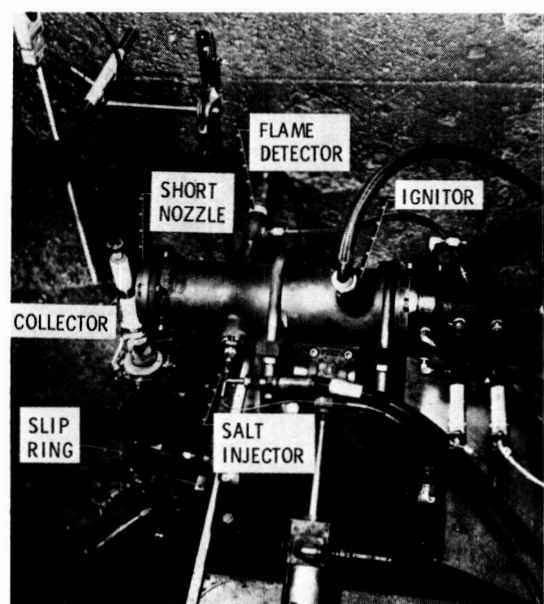
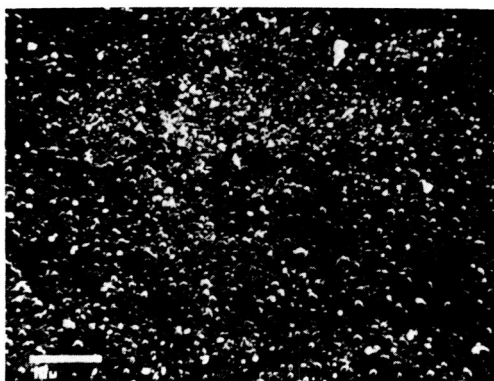


Figure 1

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NaCl PARTICLES CAPTURED



ELEMENTS DETECTED BY EDS

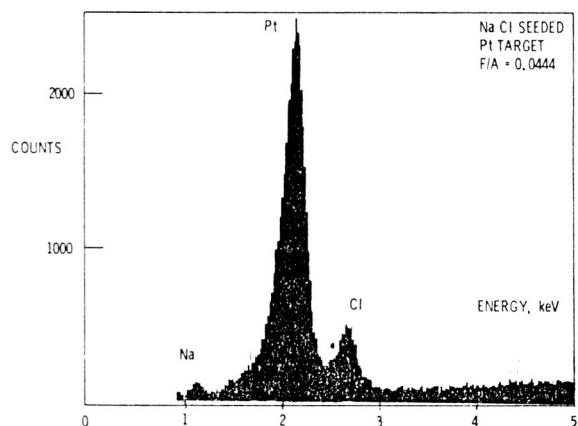


Figure 2

Na_2SO_4 DEPOSIT MORPHOLOGY FROM SODIUM ACETATE DOPED COMBUSTION GASES



Figure 3

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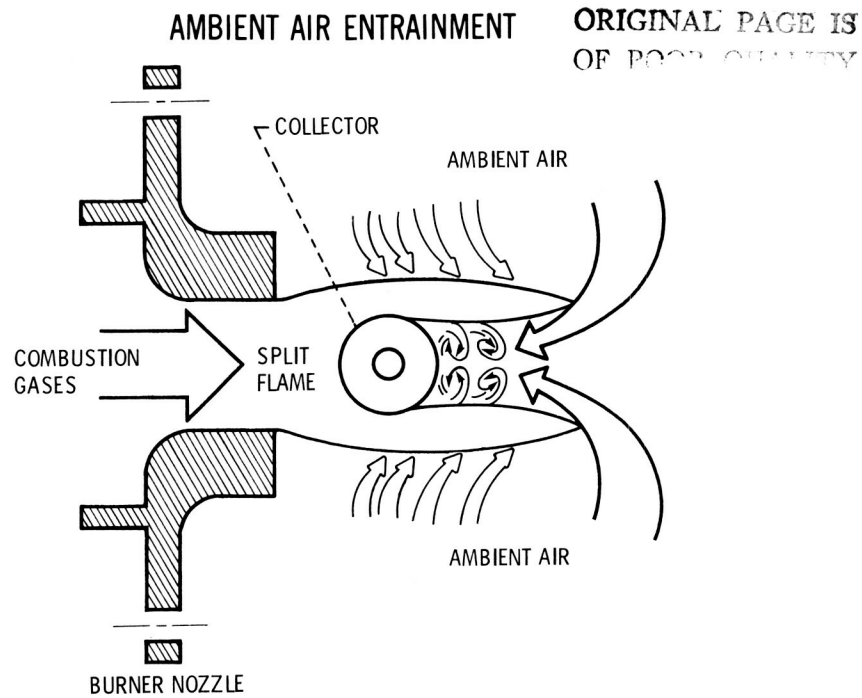


Figure 4

NAPHTHALENE CASTING APPARATUS

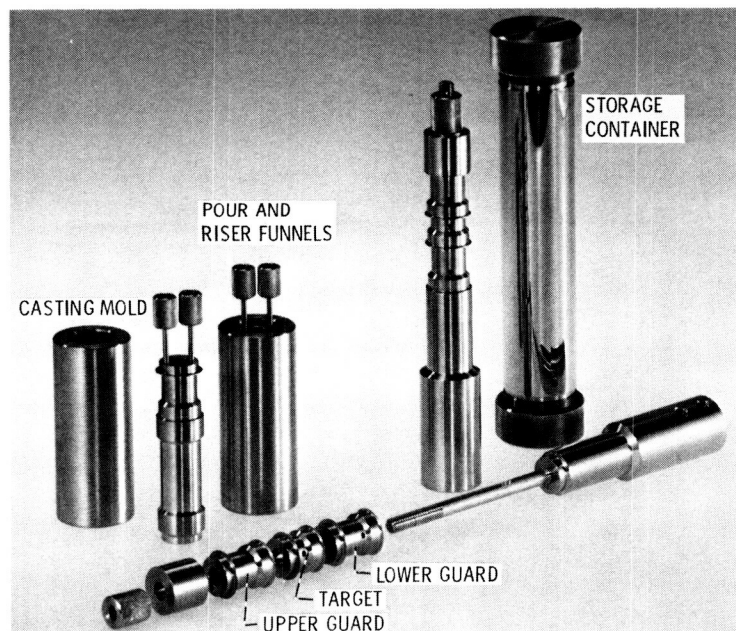


Figure 5

NAPHTHALENE SUBLIMATION TUNNEL

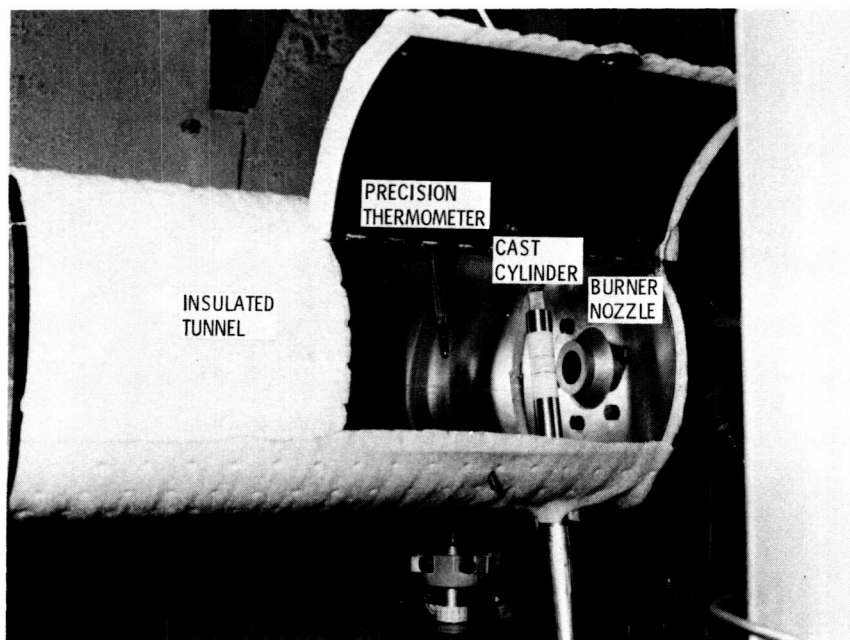


Figure 6

MASS TRANSFER NUSSELT NUMBER VS REYNOLDS NUMBER FOR BURNER RIGS

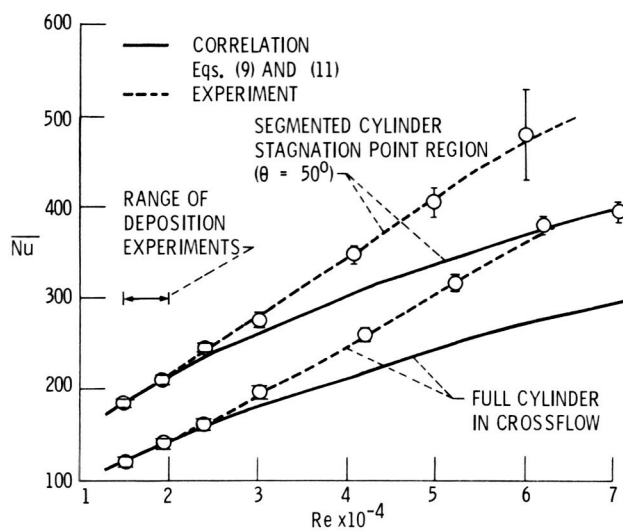


Figure 7

MAIN-STREAM TURBULENCE FACTOR VS REYNOLDS NUMBER FOR BURNER RIGS

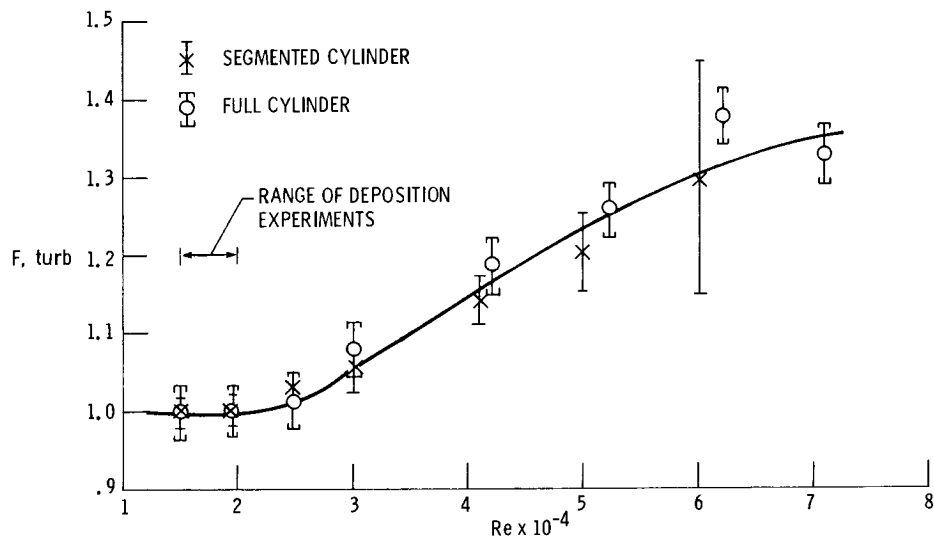


Figure 8

MAIN-STREAM COOLING AND DILUTION EFFECT

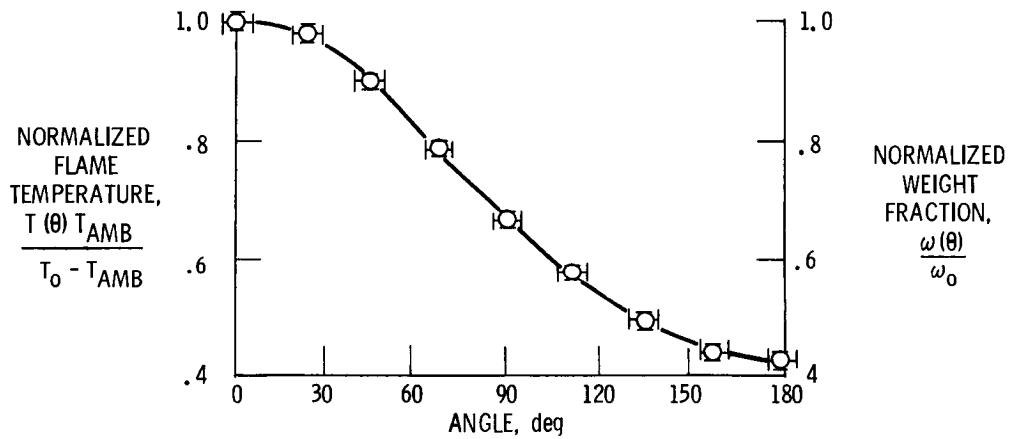


Figure 9

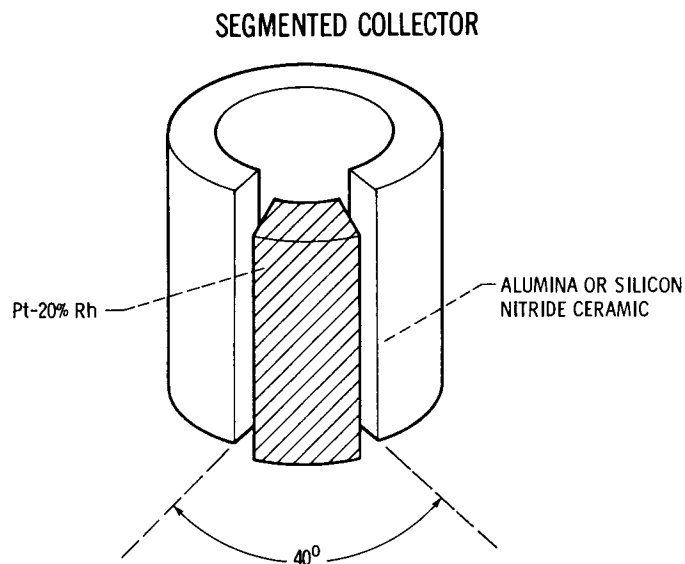


Figure 10

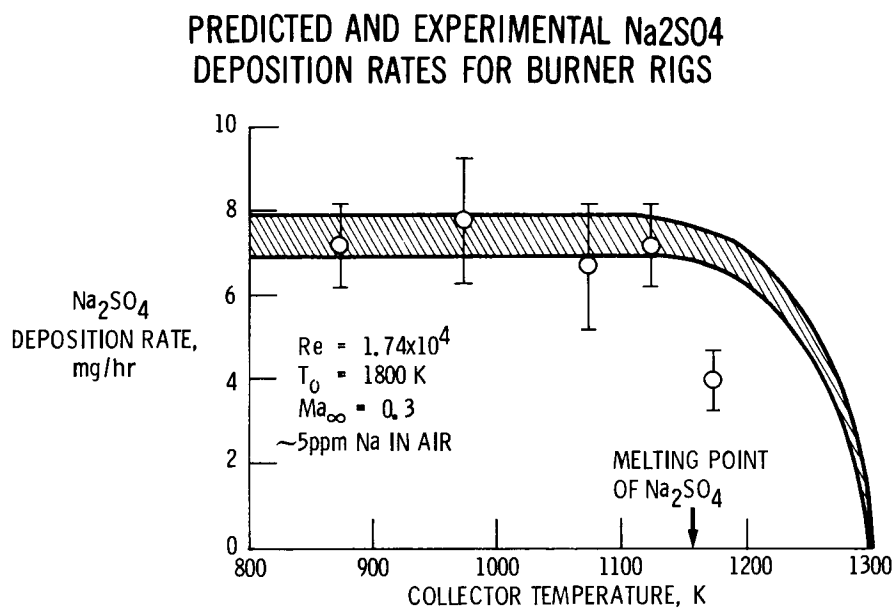


Figure 11